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RAPID DETECTION OF FALSELY MARKED BOLTS AND LARGE SCREWS

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Falsely marked steel fasteners are of concern, particularly SAE grade 5.2 threaded fasteners marked as grade 5 and grade 8.2 threaded fasteners marked as grade 8. The object of this research was to determine if an electromagnetic nondestructive test method could be used to detect falsely marked fasteners. The proposed test method consisted of measuring the impedance of a probe at two test frequencies and two magentic field levels when in close proximity to the fastener head. Test frequencies explored ranged from 1 khz to 2 Mhz. Magnetic fields ranged up to 12 kG. The 8-dimension state vector generated by this type of measurement was insufficient to sort fastener grades. The reason for this inability to sort is not because of differences in plating, but is due to the relative insensitivity of the steel electrical conductivity and magnetic permeability to fastener grade.

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INTRODUCTION

A number of steel bolts are found to be falsely marked, particularly SAE grade 8.2 bolts marked as grade 8 bolts and grade 5.2 bolts marked as grade 5 bolts. Grade 8.2 and 5.2 bolts are made from low-carbon martensite steel, fully killed, fine-grain, quenched and tempered. Grade 5 bolts are made from medium carbon steel, quenched and tempered. Grade 8 bolts are made from medium carbon alloy steel, quenched and tempered. The use of the falsely marked bolts at temperatures above 500°F may cause stress relaxation which can lead to equipment failure and even injury and loss of life. A method for rapid screening of suspect fasteners is required to verify that the grade markings on high-strength bolts and screws are correct.

The object of the research is to determine if an electromagnetic method[1] can rapidly distinguish between grade 8.2 and 8 bolts and between grade 5.2 and 5 bolts. A multi-frequency, electromagnetic test method was proposed. The proposed test consists of measuring the impedance of a probe at two different frequencies and two different magnetic field strengths when the probe is in close proximity to the fastener. The 8-dimensional state vector generated by this measurement was to be used to segregate the steel fasteners according to grade. This approach is particularly attractive since sorting would be accomplished by simply bringing a small probe to the head of the fastener without grinding or other surface preparation.

This research demonstrated that the 8-dimension state vector generated by this type of measurement is not sufficient to sort fasteners according to grade. The dual-frequency data can be used to suppress the effects of coating variations and permit measurement of the conductivity and permeability of the base material. Unfortunately, there appears to be no usable correlation between these electromagnetic properties and the grade of the bolt.

TEST METHODOLOGY

A smartEDDY 3.0 eddy-current instrument[2] was used in this investigation. The smartEDDY 3.0 is a commercially available, computer-based instrument developed and manufactured by FaAA Products Corporation[R] (FaAA). The instrument consists of an eddy-current module installed in an IBM PC-compatible computer. The instrument module contains a voltage generator, an impedance bridge, a bridge amplifier, in-phase and quadrature detectors, a multiplexer, and a 16-bit analog-to-digital converter. The instrument can generate and measure the response from two frequencies simultaneously. The test frequencies can be selected in over a wide range from 50 Hz to 10 Mhz.

In this investigation, the test probe made up one leg of the impedance bridge and the change in impedance as the test coil is brought in close proximity of the test piece was recorded and displayed. Since impedance is made up of two numbers (e.g., reactance and resistance), it can be displayed as a point on a plane. As the impedance changes, the position of the point changes tracing out a line on the screen.

Figure 1 illustrates the change in impedance as a test probe is brought in the vicinity of the head of a bolt. The data is displayed as a percent change in impedance from a reference point. The reference or balance point used in this study was the impedance of the probe when in air, far removed from any metal. As the probe is brought close to the test piece it begins to sense the test piece causing the coil impedance to change. Initially, only the coil resistance changes causing the response curve to move horizontally. However, as the probe gets closer to the test piece both the resistance and reactance increases causing the response curve to move to the right and up. The exact shape of the response curve is dependent upon the conductivity and permeability in the region interrogated by the probe.

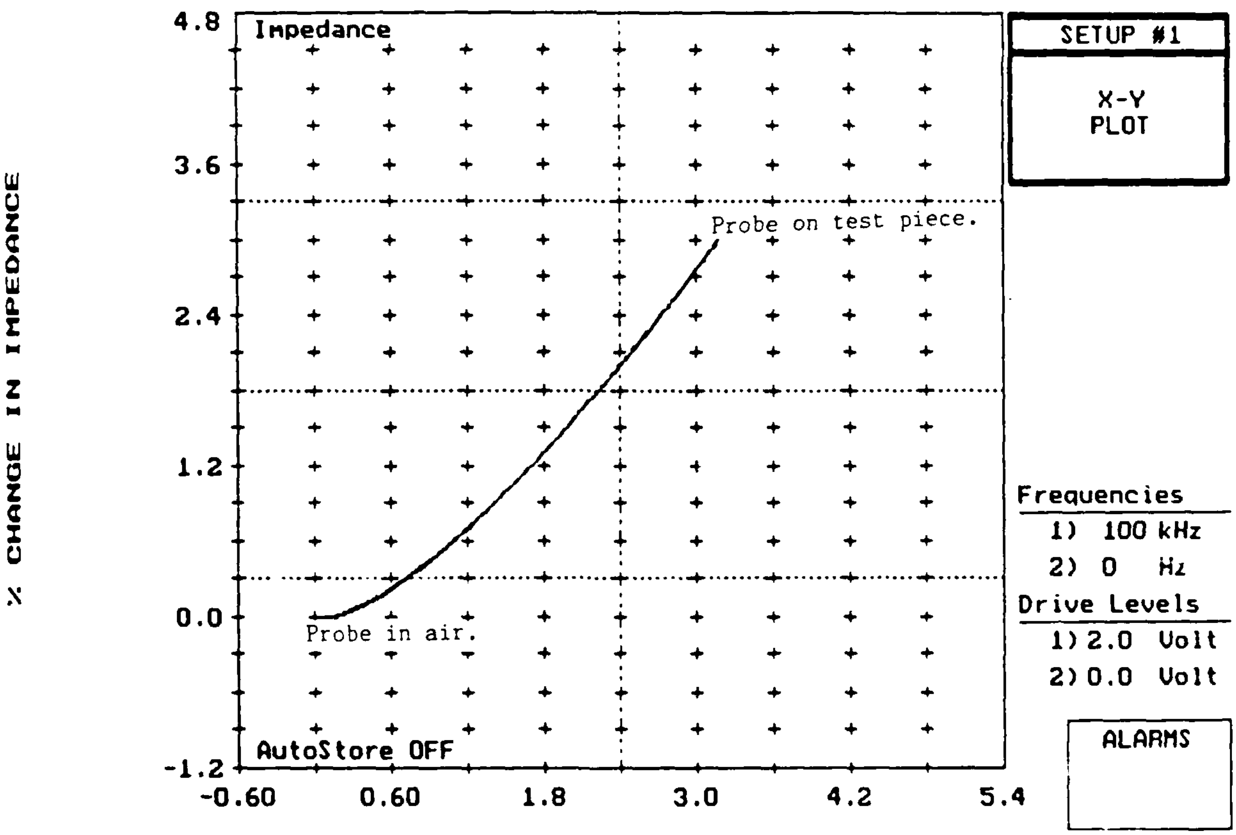

Figure 1 - Eddy-Current Response from a Steel Fastener

The electromagnetic wave generated by the test coil decays as it penetrates into a metal. The depth of penetration, often referred to as the skin depth, is dependent upon the excitation frequency.[1,3] The higher the frequency the smaller the depth of penetration. This feature can be used to separate the effects of the base material from other superficial effects, such as the effects of plating. By collecting data at two frequencies the perturbation effects of the plating and other parameters can be reduced.[3] The smartEDDY software contains a LEARN program which was used to maximize the response difference between grades.

A number of probes were used in this study. Most of the data was collected using probe FaAA P AC 20k/.125, S/N 9.34. This is a pencil probe with a built-in balance element. The coil diameter is 1/8 inch and the coil operates over a frequency range between 20 kHz and 200 kHz.

The applied magnetic field was generated with an electromagnet with 12 square-inch pole pieces. The gap between the faces of the poles is adjustable up to 4 inches. The magnetic field was measured using hall effect probe. F.W. Bell, model 4048 gauss meter was used.

The government supplied FaAA with 15 different bolt types, three of each type. Of the 15 types, four are marked as SAE grade 5, one is marked as SAE grade 5.2, three are marked as SAE grade 8.8, four are marked as SAE grade 8 and three are marked as SAE grade 8.2. The bolt types included bolts with no plating, with a cadmium plating and with a zinc plating. Table 1 summarizes the bolts used in this study.

Table 1 - Bolt Description

Bolt No.	Grade	Diameter	Length	MFR.	Plating
1a	5.2	3/8 inch	1 1/2 inch	GKW	Zinc
1b	5.2	3/8	1 1/2	GKW	Zinc
1c	5.2	3/8	1 1/2	GKW	Zinc
2a	5	5/16	2 1/4	FP	Zinc
2b	5	5/16	2 1/4	FP	Zinc
2c	5	5/16	2 1/4	FP	Zinc
3a	5	5/8	2 1/2	RSC	None
3b	5	5/8	2 1/2	RSC	None
3c	5	5/8	2 1/2	RSC	None
4a	5	7/16	2 1/4	FM	None
4b	5	7/16	2 1/4	FM	None
4c	5	7/16	2 1/4	FM	None
5a	5	5/8	2 3/4	J	Zinc
5b	5	5/8	2 3/4	J	Zinc
5c	5	5/8	2 3/4	J	Zinc
6a	8	9/16	1 1/2	M	Cad.
6b	8	9/16	1 1/2	M	Cad.
6c	8	9/16	1 1/2	M	Cad.
7a	8	1/2	2 1/2	M	None
7b	8	1/2	2 1/2	M	None
7c	8	1/2	2 1/2	M	None
8a	8	3/8	1 1/2	I	Cad.
8b	8	3/8	1 1/2	I	Cad.
8c	8	3/8	1 1/2	I	Cad.
9a	8	1/2	1 1/4	LE	None
9b	8	1/2	1 1/4	LE	None
9c	8	1/2	1 1/4	LE	None
10a	8.2	3/8	3	KS	Cad.
10b	8.2	3/8	3	KS	Cad.
10c	8.2	3/8	3	KS	Cad.
11a	8.2	7/16	2 1/2	RT	Zinc
11b	8.2	7/16	2 1/2	RT	Zinc
11c	8.2	7/16	2 1/2	RT	Zinc
12a	8.2	1/2	2	O	Zinc
12b	8.2	1/2	2	O	Zinc
12c	8.2	1/2	2	O	Zinc
13a	8.8	12 mm	25 mm	DELTA	None
13b	8.8	12	25	DELTA	None
13c	8.8	12	35	DELTA	None
14a	8.8	10	30	MAPRI	Zinc
14b	8.8	10	30	MAPRI	Zinc
14c	8.8	10	30	MAPRI	Zinc
15a	8.8	10	15	NEDUR	None
15b	8.8	10	15	NEDUR	None
15c	8.8	10	15	NEDUR	None

Grade 5, 5.2 and 8.8 are medium strength and grade 8 and 8.2 are high-strength threaded steel fasteners. Table 2 summarizes the SAE mechanical and chemical composition requirements, respectively, which are taken from SAE standard J429 and J1199 (Metric) for externally threaded fasteners.

Table 2 - SAE Mechanical Requirements

Grade	Proof Load	Tensile Strength	Yield Strength	Elong. Min.	Surface* Hardness	Core** Hardness
5(small)	85 kpsi	120 kpsi	92 kpsi	14%	54 max	C25-34
5.2	85	120	92	14	56	26-36
8.8	87	120	96	12	54	23-34
8	120	150	130	12	58.6	33-39
8.2	120	150	130	10	58.6	33-39

* Rockwell 30N
** Rockwell

It is clear that the room temperature mechanical properties can not be used to detect false bolts.

Table 3 summarizes the chemical composition of the different grades.

Table 3 - SAE Chemical Composition

Grade	Carbon Range	Mn Min.	P Max.	S Max.	B Min.
5(small)	.28-.55%	---	.048%	.05 %	------
5.2	.15-.25	.74%	.048	.058	.0005%
8.8	.15-.27	.74	.038	.048	.0003
8	.28-.55	---	.040	.045	------
8.2	.15-.25	.74	.048	.048	.0005

Based on the composition, it appears that measurement of the amount of manganese could serve as a means of detecting false bolts. However, in practice, many of the grade 5 and 8 alloys have greater than 0.74% manganese. Boron can not be used either since many of the grade 5 and 8 alloys have boron content greater than 0.0005%.

RESULTS AND DISCUSSION

One sample of each of the 15 bolt types supplied by the government were analyzed for chemical composition. Two bolts did not meet specifications. Bolt 1a had too much carbon and too little boron for a grade 5.2 bolt.. Bolt 13a had too much phosphorous for a grade 8.8 bolt. Bolt 13a chemistry would meet the specifications for a grade 5.2 bolt. Table 4 gives the measured compositions. The manganese, silicon and boron concentrations were determined using induction coupled plasma method; the carbon and sulfur concentrations were determined using LECO combustion method; and the phosphorus concentration was determined using a wet chemical analysis method.

Table 4 - Measured Chemical Composition

Bolt No.	Grade	Carbon	Mn	P	S	B
1a*	5.2	0.27	1.08	.026	.010	.00019
2a	5	0.45	0.81	.025	.021	.00036
3a	5	0.41	0.80	.028	.032	.00000
4a	5	0.33	0.80	.017	.017	.00004
5a	5	0.34	0.76	.025	.012	.00025
6a	8	0.35	1.87	.000	.015	.00019
7a	8	0.35	1.70	.017	.018	.00046
8a	8	0.42	1.63	.024	.008	.00057
9a	8	0.39	0.66	.024	.020	.00063
10a	8.2	0.24	0.87	.027	.015	.00079
11a	8.2	0.21	0.94	.025	.017	.00083
12a	8.2	0.22	0.95	.028	.011	.00093
13a**	8.8	0.24	1.29	.047	.007	.00160
14a	8.8	0.24	1.17	.033	.009	.00089
15a	8.8	0.22	0.79	.027	.032	.00089

* Does not meet specifications; carbon is greater than 0.25% and boron is less than 0.0005%.

** Does not meet specifications; phosphorus is greater than 0.038%. Note that it does meet specifications for grade 5.2.

Note the wide range of compositions characteristic of a particular grade. The only reliable indicator of alloy grade is the carbon content. The success of the proposed method depends upon the sensitivity of the alloy electrical conductivity and magnetic permeability to carbon content compared to the sensitivity to other variations.

The eddy-current response from the bolts was studied over a wide range of frequencies. Minimum frequency used was 1 kHz and the maximum frequency used was 2 Mhz. Figure 2 shows the eddy-current response from the eight types of medium strength bolts. The eight curves are generated by bringing the probe in close proximity to each of the eight bolts. From top to bottom, the curves correspond to bolt 4b, 15b, 13b, 3b, 1b, 14b, 2b and 5b. The convergence point on the left corresponds to when the probe is far from the bolts. The right-most portion of each curve corresponds to the probe in closest approach to the bolt head. Variation in the length of the curve is associated with how close the probe is brought to the bolt head.

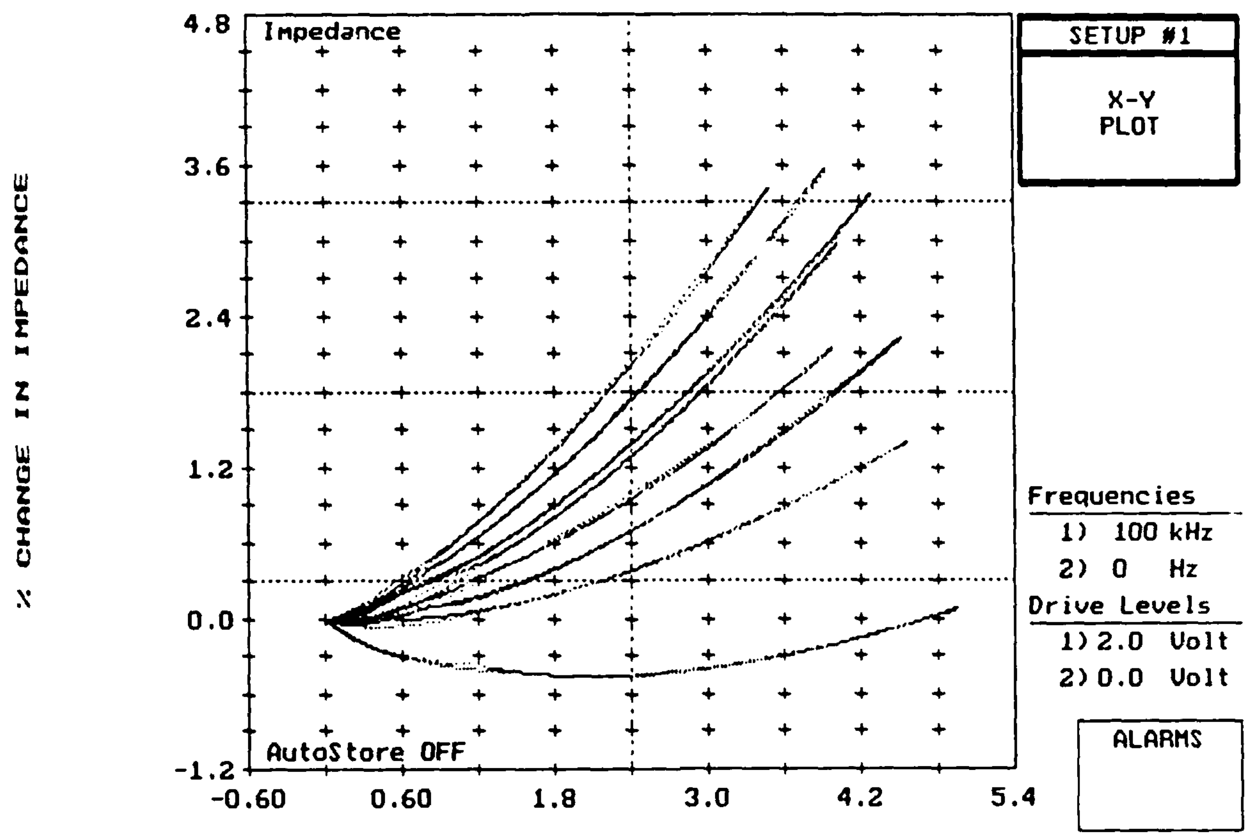

Figure 2 - Eddy-Current Response from Medium Strength Bolts

The upper four curves correspond to bolts with no plating. Note that the response curve from the grade 5 bolts (4b and 3b) bracket the response curve from the grade 8.8 bolts (15b and 13b). The same results are found over the entire frequency range. Thus, the eddy-current response from an unmagnetized bolt can not be used to sort the medium strength bolts. The shorter

length of the response curves associated with bolts 4b and 5b compared to bolts 13b and 15b initially lead us to believe that these bolts could be sorted. However, further investigation showed that the different response curve lengths were due to the nature of the markings on the top of the bolt head rather than a feature of the alloy itself. The markings prevent the probe approaching as close in the case of the grade 5 bolts.
Figure 3 shows the eddy-current response from the seven types of high-strength bolts. From top to bottom, the curves correspond to bolts 7b, 9b, 6b, and 10b. The fifth curve from the top corresponds to two bolts, 8b and 11b. The lowest curve corresponds to bolt 12b. The upper two curves correspond to grade 8 bolts without a plating (7b and 9b). The effect of a plating is to lower the signal. The next group of three curves corresponds to bolts with cadmium plating 6b, 10b and 8b. Note that the response curve from bolt 10b (grade 8.2 bolt) is bracketed by the response from two different grade 8 bolts.

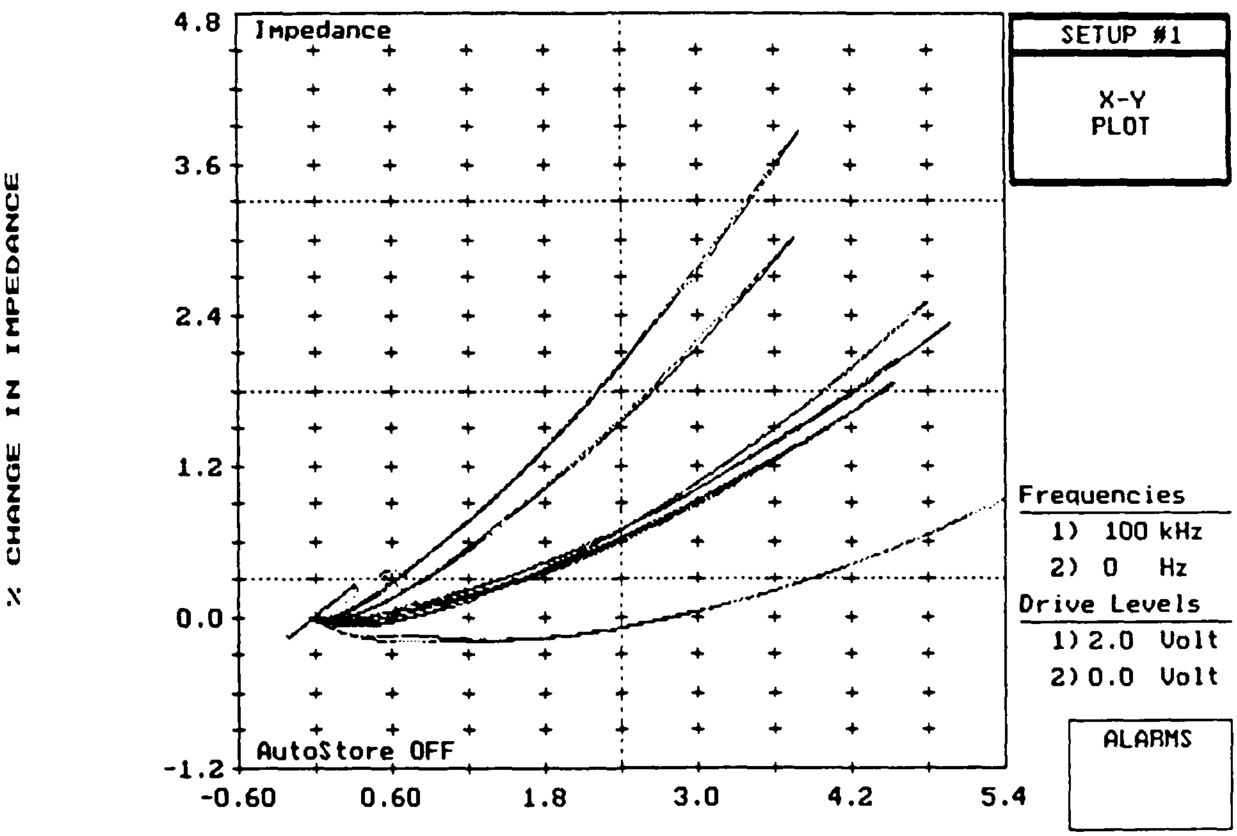

Figure 3 - Eddy-Current Response from High-Strength Bolts

The smartEDDY LEARN routine was used to determine if a mixture of two frequencies could be used to separate the bolt grades. No two-frequency mixture was found which permitted grade sorting. There is not sufficient correlation between the eddy-current response and the steel grade to permit sorting.

It was anticipated that the presence of different plating would confound the eddy-current signal. The plan was to use the response at two frequency to separate out the effects of the coating. However, it appeared that we had a more serious problem in that the eddy-current response from the base steel was not sufficiently different to permit sorting. To eliminate the effect of coating variation, or other superficial surface effects, we ground off the as-received surface of selected bolts.

Figure 4 shows the response from four high-strength bolts with their as-received surfaces removed. The upper two curves corresponds to bolts 6a and 7a. The lower curve corresponds to the response from two different bolts 9a and 12a. Note that bolts 6a and 7a are grade 8 bolts manufactured by the same vender. The lower response curve corresponds to both a grade 8 and grade 8.2 bolt.

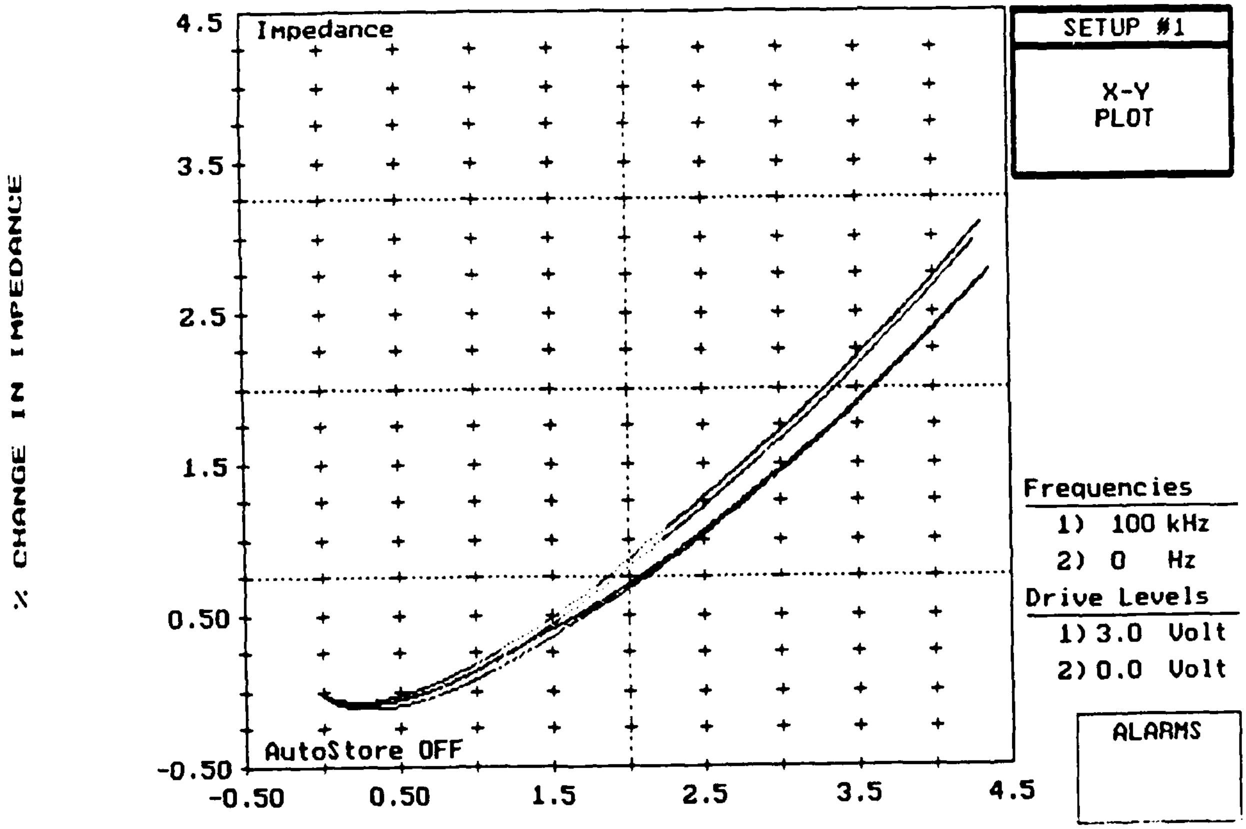

Figure 4 - Eddy-Current Response from High-Strength Bolts with As-Received Surfaces Removed

Figure 5 shows the eddy-current response from three additional high-strength bolts with their as-received surfaces removed. From top to bottom the response curves correspond to bolts 10a, 8a and 11a. Note that the response curves from the grade 8.2 (bolts 10a and 11a) bracket the response from the grade 8 bolt. It is evident that the unmagnetized eddy-current response can not be used to sort the bolt grades of interest.

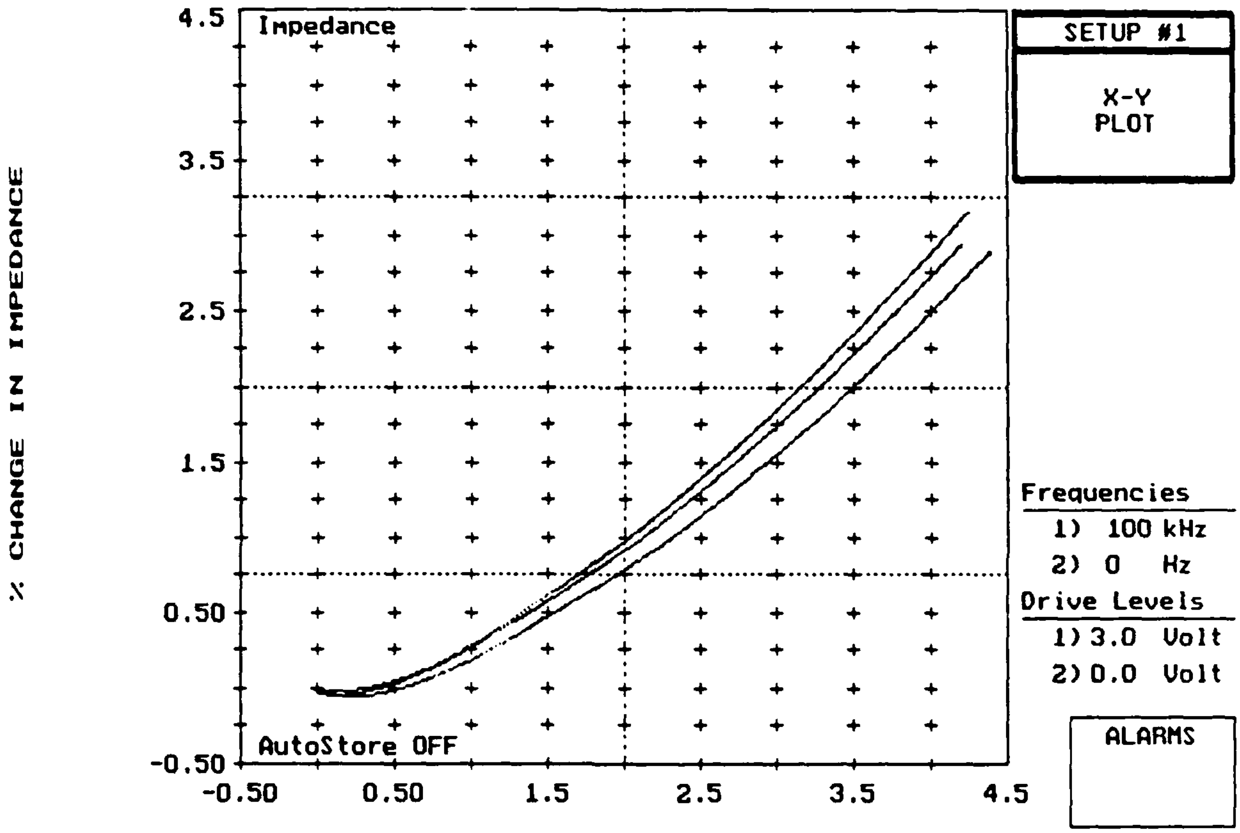

Figure 5 - Eddy-Current Response from High-Strength Bolts with As-Received Surfaces Removed

The remaining question is, can a magnetized eddy-current response be used to sort the bolts. It is well known that the magnetization curve and hence the differential permeability is sensitive to chemistry and other properties of the steel alloy. Furthermore, that the eddy-current response is strongly dependent upon the differential permeability.

Figure 6 shows the eddy-current response from a grade 8 steel in different magnetic fields ranging up to 12 kG. The upper curve is the eddy-current response in zero magnetic field and the sequence of curves are the eddy-current response as the magnetic

field is increased in one kG step. The different response curves result from the decreasing differential permeability as the applied magnetic field is increased.

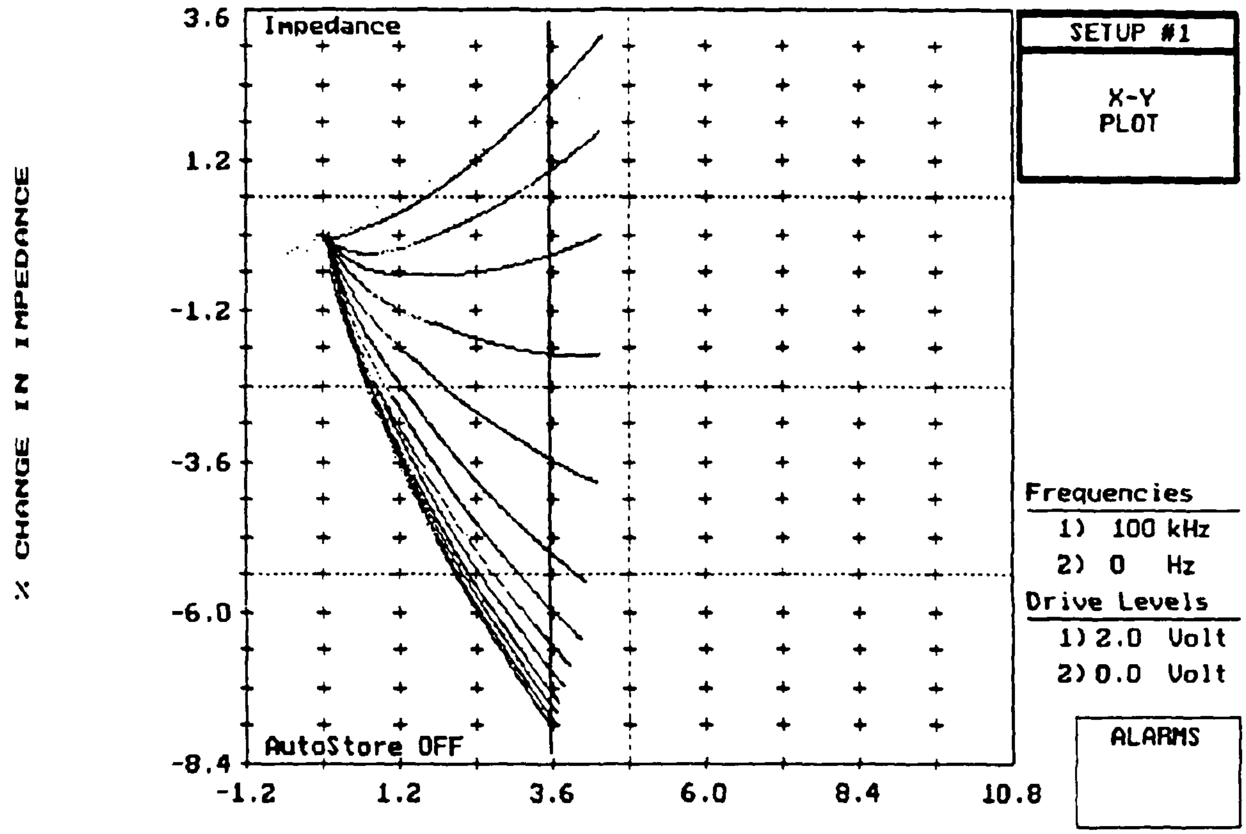

Figure 6 - Eddy-Current Response from a High-Strength Bolt in Different Magnetic Fields

Another representation of the eddy-current response is to record the change in reactance (vertical component of the impedance) at a fixed change in resistance. Figure 7 compares the measured reactance at a resistance of 3.5% for three different grade 8 bolts and a grade 8.2 bolt. The shaded area marks the range in response from the three grade 8 bolts (bolts 6a, 7a, and 9a) as a function of applied magnetic field. The solid points mark the response from a grade 8.2 bolt (bolt 12a). It is evident that the eddy-current response from the grade 8.2 bolt is bracketed by the response from the grade 8 bolts over the entire range of applied magnetic fields from 0 to 12 kG.

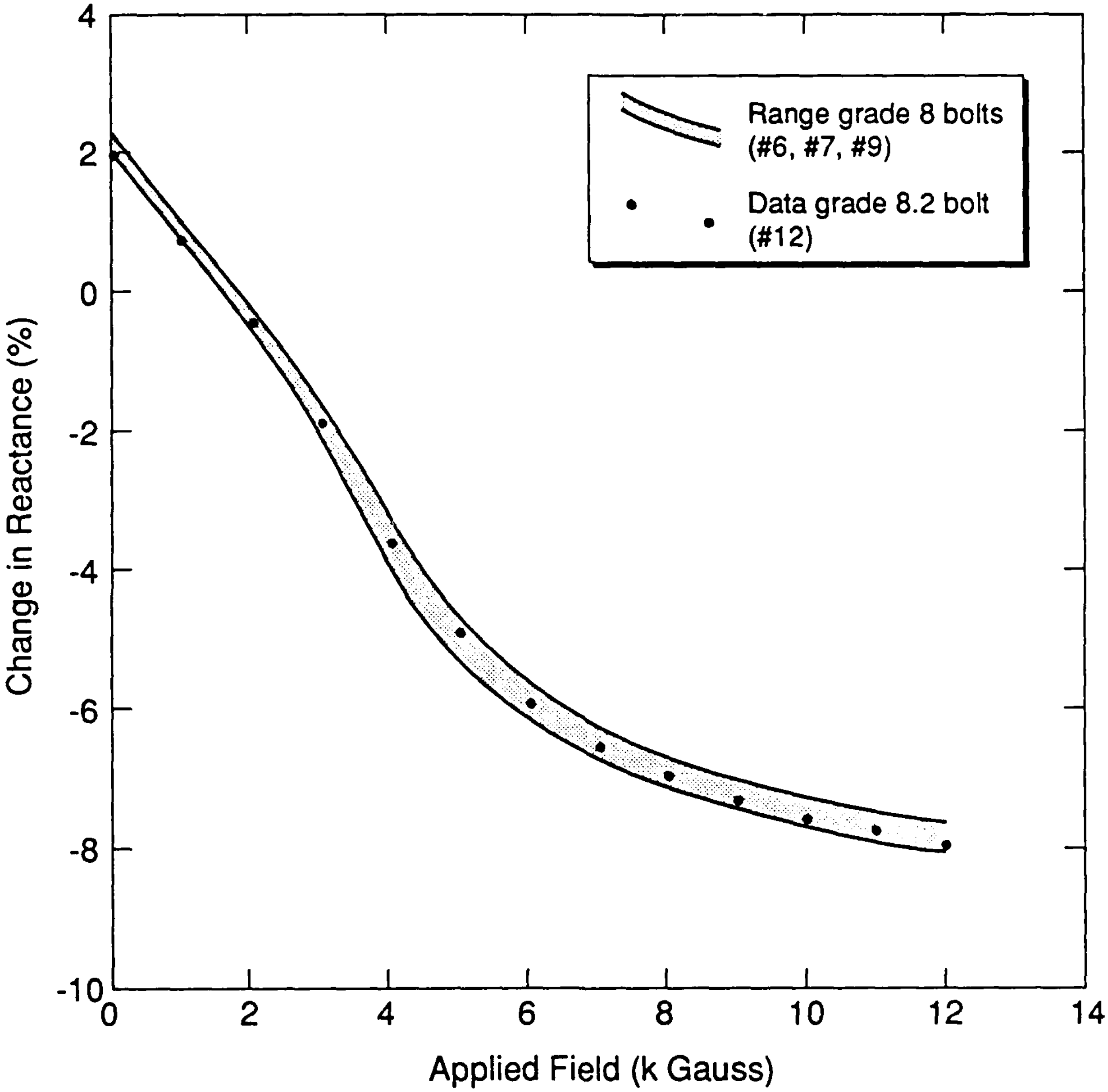

Figure 7 - Comparison of eddy current response from grade 8 and 8.2 bolts

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CONCLUSIONS

Based on the results of this study we have concluded that the eddy-current response cannot be used to sort between grade 5 and 5.2 bolts or between grade 8 and 8.2 bolts. The reason for this inability to sort is not because of the different possible coatings but is due to the relative insensitivity of the electrical conductivity and magnetic permeability to steel grade when compared to the variability in these electromagnetic quantities within the same grade of bolt.

REFERENCES

[1] Nondestructive Testing Handbook, 2cd addition, Volume 4, Electromagnetic Testing, 1986.

[2] A brochure describing the smartEDDY 3.0 can be obtained from FaAA Products Corporation[R], 149 Commonwealth Drive, Menlo Park, CA 94025 or by calling (415)688-7181.

[3] Introduction to Electromagnetic Nondestructive Test Methods, H.L. Libby, New York, 1979.

[4] A brochure describing the smartEDDY software can be obtained from FaAA Products Corporation[R], 149 Commonwealth Drive, Menlo Park, CA 94025 or by calling (415)688-7181.